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Profit Regulation of Defense Contractors and Prizes for Innovation

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PREFACE

This report is part of a larger project on the economics of defense acquisition. It was sponsored by the Assistant Secretary of Defense, Program Analysis and Evaluation, and was carried out in the Acquisition and Support Policy Program of RAND's National Defense Research Institute, a federally funded research and development center supported by the Secretary of Defense and the Joint Staff. The publication should be of interest to anyone concerned about profit policy effects on defense sector profitability and investment incentives.

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SUMMARY

The defense sector is subject to a form of cost-based economic regulation, just as public utilities are. A set of regulations that are as detailed, all-encompassing, and arcane as any that can be found in other regulated sectors determines the prices that defense contractors will receive for their products. These regulations are often referred to as the Department of Defense (DoD) "profit policy." Although economists have made great strides in analyzing the nature of the regulatory problem in several industries, little attention has been devoted to the defense sector. The goal of this report is to describe and empirically investigate an extremely simple theory that captures an important aspect of the nature of the regulatory problem in defense contracting.

The theory describes a critical difference between the regulatory problems in defense and public utilities and therefore suggests why different rules and institutions might be appropriate in each case. Furthermore, it yields several implications regarding how an optimal regulatory policy should be structured and sheds light on current policy debates over DoD profit policy. A large part of the document is devoted to empirically verifying that the incentives posited by the theory exist and are large.

The theory is simply that profit regulation of defense contractors is structured (and necessarily must be structured) so that firms generating valuable new innovations will receive large rewards. That is, profit regulation of defense contractors must establish large prizes for innovation. Innovation is a major product of defense contractors. However, it is difficult to directly purchase effort directed at innovation for two separate reasons. First, there is a moral hazard problem. A firm's effort level directed toward innovation is difficult to observe directly, and the level of innovation produced is only stochastically related to the level of innovative effort. Second, firms are likely to have private information about the probable value of various potential avenues of research. An optimal R&D program should attempt to use this private information by decentralizing some R&D decisions and giving private decisionmakers incentives to choose the best avenues of research from government's perspective.

Any scheme that proposes to reward "good" ideas immediately faces the problem of finding an objectively verifiable measure of "good." The natural solution in this case is to use as an indicator of its quality

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whether the idea is adopted or not. Thus the existing regulatory scheme creates prizes for innovation by guaranteeing that any firm becoming a prime contractor on a new weapon system will earn positive economic profit on the production contracts for the weapon system. Firms that can successfully generate ideas good enough for the government to adopt receive prizes in the form of economic profit on the production phase of the system.

A rent-seeking model captures the situation induced by the current regulatory structure. Firms compete for prizes by spending money on innovation. An increase in the level of economic profit defense contractors are allowed to earn would have two effects. In the short run, existing firms would compete more vigorously among themselves to develop ideas that could be accepted for production. Even in the short run, an increase in allowed profit levels on production contracts would be at least partly transformed into increased expenditures on innovation. If firms were still earning economic profit, then in the long run more firms would enter the industry and compete for the prizes as well until the industry was restored to zero profits.

If this view is correct, profit policy may have little, if any, effect on the long-run profitability of the defense industry. Rather, its more important long-run effect may be to regulate the pace of innovation.

Stock price data on firms competing for 12 major aerospace contracts are analyzed to empirically measure the size of prizes induced by the current regulatory structure. A theory explaining how to calculate the size of a prize based on the observed changes in contestants' market values is first developed. Then the changes in market values are measured and the implied size of the prizes calculated. A conservative estimate of the size of the prize associated with the average contest is $67 million. This is about 15 percent of the market value of the average competing firm. Furthermore it is 4.6 percent of the expected discounted revenues the average winning firm would receive from the project, which means that 4.6 cents of every dollar of revenues the winning firm receives from producing the system is pure economic profit.

This report does not directly address the question of whether the current level of prizes is too high or low. It merely attempts to establish the theoretical link between prizes and innovation and then show that prize levels induced by the current rules are large enough to make a theoretical analysis of the role of these prizes important. To answer the question of whether the prizes are too large or too small would require an assessment of the adequacy of the current level of innovation, which is clearly beyond the scope of this study.

Furthermore, a prize system will also necessarily generate some less-desirable forms of rent-seeking behavior such as influence-seeking behavior directed toward members of Congress. An overall determination of the optimal prize level would have to consider this as well.

ACKNOWLEDGMENTS

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1. BACKGROUND

THE ACQUISITION CYCLE

This section describes the typical acquisition cycle for a major aerospace system.[1] The F-16 will be used as an example since its procurement was relatively typical. The Department of Defense (DoD) divides the procurement process into four phases with a "milestone" marking the beginning of each new phase. The milestones are identified because a system must pass on upper-level review to proceed from one phase to another. The milestones are numbered 0 through III and the phases from first to last are called concept exploration, demonstration and validation, full-scale development, and full-rate production.

Milestone 0 marks the beginning of research and development specifically targeted toward a new system. To pass milestone 0, a service must demonstrate a need for a new type of system. Thus activity before milestone 0 consists largely of consensus building within the services and DoD over what sorts of needs are most urgent.

In the late 1960s, the fighters then being developed by the Navy and Air Force (the F-14 and F-15) were large, heavy airplanes with extensive and elaborate avionics.[2] They could deliver large payloads of weapons over long distances and also had extensive beyond-visual-range capabilities (the ability to detect and destroy an opposing fighter well before visual contact can be made). However, these fighters were extremely expensive and not particularly maneuverable, thus not well suited to engaging enemy aircraft at close range in dog-fights. Further, their beyond-visual-range capabilities were not as effective as had been hoped because, among other things, pilots were reluctant to fire at a target until they could visually determine if it was a friend or foe.[3] In the late 1960s a consensus began to emerge that what was required was a smaller, more maneuverable aircraft with less-extensive beyond-visual-range capabilities and costing considerably less than the F-14 and F-15.

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[1]This section relies heavily on Smith and Friedman (1980) and Smith et al. (1981).

[2]Radar and other electronic equipment.

[3]See Smith et al. (1981) and Fallows (1981) for more extensive discussion.

Even at this early (before milestone 0) stage, contractors were heavily involved (at their own cost) in preliminary design studies exploring what such a fighter might look like. Both Northrop and General Dynamics (G.D.) actually used their own funds to create detailed designs at this point.

Milestone 0 was passed in March of 1970[4] when the DoD began funding research studies on aspects of the proposed fighter concept, which was termed the light weight fighter (LWF). There is considerable evidence that companies were also spending their own money to attempt to increase their chances of becoming the prime contractor during this phase. For example, Lockheed and Northrop submitted design proposals for the new aircraft that the DoD had not directly solicited or funded. In January of 1971, the DoD formally requested that all interested contractors submit detailed proposals describing proposed designs for the new fighter. The firms submitting the two best proposals would be selected to continue into the next phase. Out of the five firms submitting proposals, the DoD selected G.D. and Northrop in April 1972.[5] This was milestone I.

In a RAND case study of the F-16, the role of the activity before milestone I is summed up as follows.

> That several-year period of studies and unsolicited proposals played a critical role in the evolution of the LWF prototype program by providing an extensive body of information for use in developing system requirements. Therefore when the call went out for candidate systems, the LWF advocates were ready with a concept that was well developed both in technical and operational terms and that had the backing of key personnel at many levels of the DoD.[6]

In particular, the involved contractors were not simply passively performing design studies that they were hired to do. They were aggressively attempting to create designs that the DoD would accept.

During the demonstration and validation phase, G.D. and Northrop each built two prototypes that the DoD then ran through a series of tests. The prototypes were said to be "austere" in the sense that they consisted of the basic air platform without weapons or avionics. The government largely paid for the cost of building the prototypes. G.D. was awarded $37.9 million and Northrop received $39.1 million.

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[4]The milestone system was not adopted by the DoD until late in 1971, at which time the F-16 had already progressed through what would have been milestones 0 and I. Therefore, the first two milestones have been placed at the approximate dates they would have occurred had the system been in place.

[5]The other three contestants were Boeing, LTV, and Lockheed.

[6]Smith et al. (1981), p. 85.

However, the contracts with G.D. and Northrop imposed no specific obligations on either contractor to produce anything. Rather, once again, the DoD was relying on the fact that both contractors had large incentives to do exactly what the DoD wanted done.

> The Air Force told the bidders that they could fulfill their contractual obligation by "delivering a flatbed of bolts" if that represented their best effort using the contractual amount. However . . . the competitive environment insured that [producing a fighter the government wanted] would be the real goal (not "best effort") to which corporate funds would be committed if necessary. The importance in this arrangement of the potential for follow-on work cannot be overestimated. That is, if the program had clearly provided no expectation of follow-up business, the contractors would have had little motivation to devote so much of their talent and money.[7]

Milestone II occurred in January of 1975 when G.D. was selected to produce the F-16. During full-scale development, G.D. integrated the weapons and avionics systems into the fighter, corrected some problems that had become apparent from the prototype tests, built the production line to produce the F-16, and produced the first eight airplanes. Milestone III occurred in October 1977 when the DoD decided to authorize full-rate production of the fighter. The first production aircraft flew in August of 1978, and approximately 120 per year have been delivered since then. At the end of 1986, the government had purchased 1073 F-16s, and current plans are to purchase a total of 2729.[8] Thus production will continue well into the 1990s.

A number of points should be noted about the acquisition process as described above. First, typically about 10 percent of the costs of the project occur before milestone II and 90 percent occur after. Full-scale development is the first phase of the project involving large amounts of money. This explains why the DoD typically carries competition no further than milestone II.

Second, the point at which a single prime contractor is selected has varied between projects. In the 1960s, there was no prototype competition; very elaborate "paper competitions," where firms submitted extremely detailed design proposals, were used to select a prime contractor at milestone I. In some rare instances, in the 1970s, competition was actually maintained until milestone III.[9] However, in all 12 systems considered in this study there was always a well-defined "final contest" with the following characteristics:

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[7]Ibid.

[8]General Dynamics (1986).

[9]The UH-60 and AH-64 helicopters.

- All contestants were known because each submitted a "final product" to the DoD for evaluation, which was a paper design study, prototype, or even an entire functioning factory, depending on the contest.

- There was a well-defined date on which the DoD announced a single winner from the group of contestants.

Third, at milestone II, the DoD signed a contract with G.D. essentially establishing a fixed price for full-scale development and for the first three years of production.[10] However, contracts for production of the annual lots in years four and thereafter were left to be negotiated by G.D. and the DoD on an annual basis. This situation is the rule. In fact, in many cases only the full-scale development contract is signed at milestone II, and all production contracts are left to be negotiated on an annual basis. Ideally, the DoD would like to be able to sign a single contract covering both full-scale development and all production when there are still two or more firms competing for the contract. Furthermore, private firms might even prefer that such a long-term contract be signed. After a single firm has set up a production line and other competitors' design teams have been disbanded, there is only one possible source for the weapon. However, there is only one possible buyer.[11] Such a one-on-one situation creates potential "hold-up" problems on both sides, so that both parties might prefer the certainty that a long-term contract could offer.[12]

However, long-term production contracts are not possible for a number of reasons. Because of technical advances, the nature of the airplane is constantly evolving in ways that substantially affect the cost of production. These cannot be anticipated and included in a contract. Furthermore, the DoD cannot predict Congressional funding levels. Even if the DoD were willing to commit to purchasing 200 airplanes per year of a fixed design for ten years, it does not have authority to commit funds to do this. Finally, the DoD's own requirements are constantly changing as the nature of the perceived threat changes, and a contract committing it to a course of action for ten or more years would probably not be optimal even if Congress would allow it. Therefore, an important aspect of the procurement process is that most production contracts are signed annually in a sole-source, sole-buyer environment.

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[10]Actually, there was a very small amount of cost sharing, and the three production contracts were options for the government to exercise. See Smith et al. (1981) for details.

[11]Even when foreign sales are a possibility the DoD must approve them.

[12]See Williamson (1975) for a thorough discussion of the "hold-up" problem.

Fourth, in the case of the F-16, the competing firms had a strong desire to be awarded the contract, and that motivated them to devote large amounts of time and money toward innovation. That in turn played an important role in assuring the success of the project.

THE REGULATORY CONTRACT

As in any cost-based regulatory system, the DoD regulations specify procedures for calculating the cost (and price) of producing a weapon system given the production technology being used. These regulations must confront the same sorts of issues faced in other regulated industries. How should joint costs be allocated between defense and nondefense work and between various defense projects? How should capital be depreciated? What sorts of costs should not be allowed? What is the cost of capital?

The entire set of regulations governing defense procurement is codified in the *Code of Federal Regulations, Title 48*, chapters 1–2. The nature of these regulations will not be described in any detail here. The regulations are distinctly different in many respects from the rules used in public utility regulation. Broadly speaking, they reimburse contractors for most operating costs plus give them a "fee" or "profit" that is a complicated function of various classes of operating and capital costs.[13] The rules for calculating the fee or profit are often referred to as profit policy.

Goldberg's (1976) insightful theory of regulation as an administered contract represents the best way to understand the effect of these regulations on the procurement process. In Goldberg's view, an implicit long-run contract exists between the regulator and regulated firm. It describes how the regulator will treat the regulated firm over time in varying circumstances and conditions. The codified regulatory structure often describes important aspects of this implicit contract. For example, in public utility regulation the implicit contract can be viewed as the regulator's commitment to review the utility's rate structure periodically and adjust prices to guarantee that the firm will earn a fair rate of return on its capital. Utilities will invest in long-lived capital equipment only because they believe the government will honor this implicit contract.

Regulations play an analogous role in defense procurement. The implicit contract between the DoD and defense contractors is that when contracts are negotiated, the DoD's negotiation objective will *not* be to

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[13]See Rogerson (1992b, 1992c) for a more detailed discussion of these regulations.

get the absolutely lowest price possible on that contract. Rather, the DoD's objective will be to pay the contractor a "fair" price, where "fair" is determined by pricing rules in the regulations. Regulations are explicit on this point. For example, the preamble to profit policy regulations includes the following statement.

> Effective national defense in a free enterprise economy requires that the best industrial capabilities be attracted to defense contracts. These capabilities will be driven away from the defense market if defense contracts are characterized by low profit opportunities. Consequently, negotiations aimed merely at reducing prices by reducing profits with no realization of the function of profit, cannot be condoned.[14]

Thus pricing regulations can be viewed as playing two roles in the procurement process. First, when the government actually signs some form of cost-reimbursement contract with a firm for a project, these regulations determine which costs will be reimbursed and to what extent. However, and much more important, these regulations describe government's implicit commitment as to how it will reimburse firms when it negotiates other contracts in the future.

Pricing regulations thus represent government's promise to choose a target when it negotiates the price of a contract with a firm. The outcome of the negotiation depends not only on the government's negotiation target but also on the relative negotiation strengths of the two parties. For example, if the government needs a particular system very badly, and no other firm is able to produce this system or a good substitute, the firm producing this system should do much better in the annual negotiations determining the price of that year's production. Pricing regulations therefore represent an important, but not the only, factor determining the price a firm will actually receive on the series of annual production contracts for a given weapon system.

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[14]*Code of Federal Regulations, Title 48*, 215.901 (c).

2. THEORY

The standard regulated public utility is engaged in a one-step process—production. The regulator attempts (among other things) to guarantee that the regulated firm earns zero economic profit on this step. The defense sector is engaged in a two-step process—innovation and production. The first step is at least as important as the second. In fact, a basic assumption underlying current U.S. defense policy is that the optimal strategy involves having a smaller number of more technically sophisticated weapons than the enemy. Given this strategy, it is critically important for the United States to maintain an innovative lead. The DoD must find some way to induce defense contractors to exert large amounts of effort directed toward generating the types of innovations that the DoD would find most useful. A good regulatory policy would still presumably attempt to guarantee that regulated defense firms earn zero economic profit overall. However, there is no reason to require that firms earn zero profits on each step. In fact, the major theoretical point of this study is that there is a very good reason to structure the regulatory process so that negative economic profit is earned in the innovation phase and positive profit is earned in the production phase. The theory is presented in four parts.

PART 1: PRIZES FOR INNOVATION ARE REQUIRED

The DoD is unable to directly purchase the innovative efforts of firms and must therefore indirectly give firms the incentive to provide this effort by establishing rewards for successful innovation. This is true for two reasons.

First, there is a moral hazard problem. Since it is difficult to monitor the level of effort a firm is exerting, the DoD must give firms an incentive to exert this effort by promising to reward successful innovation with prizes.

However, even if level of effort was totally observable, a second factor would still necessitate the use of prizes. Firms are very likely to possess private information about which sorts of projects are more likely to yield the kinds of results of most value to the DoD. The following stylized example serves to illustrate this idea. Suppose that exerting effort consisted only of spending money, and the DoD could exactly monitor the amount of money spent. Furthermore, assume that two

possible projects exist for a firm to explore, projects A and B. Assume as well that the DoD can monitor whether money is spent on project A or B. In this situation the DoD could simply order the firm to exert given levels of effort on each project and monitor that this occurred. Now suppose that project A is likely to produce high benefits to the DoD but will yield very few commercial spinoffs for the firm. Project B is the reverse. It is likely to produce very low benefits for the DoD but will yield several useful ideas that the firm can use in its commercial business. Furthermore, suppose that because of its greater technical expertise only the firm is aware of this fact. Both projects appear to be similar to the DoD. If the firm were simply hired to perform research (which is possible by assumption because research effort is directly monitorable), the firm would have an incentive to recommend project B. To give the firm an incentive to choose project A, the DoD must pay the firm according to the value of the ideas produced, not according to the amount of effort it exerts. That is, successful innovations must be rewarded with some sort of prize.

Another way of stating this second point is that an optimal research program should be somewhat decentralized so that firms can make decisions based upon their private information. However, when delegating some decisionmaking to firms, the DoD must simultaneously provide firms with incentives to make the decisions that are best from the DoD perspective. Establishing prizes for innovation accomplishes this. An example is that companies will often fund prototypes for a particular system that they believe has great potential even if no one in the DoD at that time yet agrees.[1] When there are prizes for successful innovation, firms have an incentive to use their own funds if necessary to pursue research projects that they strongly believe will eventually yield results of great value to the DoD.

PART 2: A REGULATORY STRUCTURE THAT DIRECTLY PROVIDES LARGER PRIZES FOR HIGHER QUALITY INNOVATIONS IS NOT POSSIBLE

The argument of Part 1 does not by itself establish the regulatory principle that defense firms should earn positive profits on production contracts. In principle, government could commit to R&D incentive

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[1]For example, several prototype predecessors of the F-16 and AH-64 were privately funded by firms. See Smith et al. (1981), pp. 84 and 155–158.

contracts of the form w(x), where x ε X, X is the space of all possible innovations, and w(x) is the wage the contractor will receive if the innovation x results. Then production contracts could be priced to yield zero economic profit, and the payment of higher wages to more valuable innovations would provide the incentive for innovation. Furthermore, w(x) could be chosen so firms were just willing to perform the R&D and thus earned zero economic profit in the R&D phase as well.

However, the transactions costs of writing out a legally enforceable, objectively verifiable contract describing all possible innovations and the price that would be paid for each one would be prohibitively costly, if not impossible, for all but the most trivially simple R&D projects. Some R&D occurs within well-defined programs with fairly well-defined objectives. Even in those cases, the DoD is unlikely to be able to provide a legally enforceable contract covering all possible design improvements. However, a large fraction of firms' R&D is directed toward identifying more basic new ideas and concepts for weapon development. As explained above, the R&D process is somewhat decentralized to allow firms to use their own private information in deciding which avenues of R&D to explore. To sign a legally enforceable contract directly rewarding the results of this more far-ranging basic R&D would require the government to list the possible universe of innovations and the prize attached to each one. This is obviously impossible.

One other option would be for government to simply announce that it will evaluate the quality of each new innovation and award a prize based on the evaluated quality. One might imagine creation of a "DoD prize panel," which annually assessed the results of all firms' efforts and awarded prizes accordingly. Such a scheme would probably be totally infeasible because of the subjectivity of any such evaluation. Firms would all claim their research was unfairly evaluated, and one could imagine endless Congressional investigations into such a scheme. (It might also be politically difficult to award large prizes.)

Transactions costs prevent the writing of legally enforceable contracts that directly reward innovation. The option of relying on the government to evaluate each innovation and assign it a "fair" reward based on its quality is too subjective to work. Therefore, it is not possible to directly pay larger prizes for higher-quality innovations.

PART 3: CONTRACTS THAT PROVIDE ECONOMIC PROFIT ON PRODUCTION CONTRACTS WILL PROVIDE PRIZES FOR GOOD INNOVATIONS AND LARGER PRIZES FOR MORE IMPORTANT INNOVATIONS

The obvious objectively verifiable signal of whether a firm has created a successful new weapon design is whether the DoD chooses to purchase it. A regulatory system could create prizes for innovation by guaranteeing that any firm becoming a prime contractor on a new weapon system will earn positive economic profit on the production contracts for that system. In such a system, firms that can successfully generate ideas good enough for the government to adopt would receive prizes in the form of economic profit on the production phase of the system.

Furthermore, if profit is awarded approximately as a percentage of cost (the profit earned on a system doubles if the system is twice as expensive), this might in a very rough sense also tend to award larger prizes for better innovations for two reasons. First, systems that prove to be useful will be purchased in larger quantities. Second, there is probably some sense in which a $30 billion project is more important to government than a $30 million project.

It is important that any regulatory system provide the firm with incentives to devote effort to innovation even after it is selected as the prime contractor for two reasons: First, since the prime contractor is typically chosen before full-scale development, it must often perform substantial development work before production begins. Second, constant upgrading of systems in production is a very important part of the innovative effort in defense procurement. A regulatory system that provides economic profit approximately equal to a percentage of cost gives incentives for both types of effort. During full-scale development, the lure of positive economic profit on production contracts will ensure that the firm exerts effort toward making the project a success. During production, a firm that improves the system will guarantee more sales and thus more profit.

An explicit design competition is not essential for economic profit to create incentives for innovation. The firm must perceive that its chances of being awarded production contracts will increase if it exerts more innovative effort. An explicit design competition in which only one winner will be chosen clearly does this. However, even after the prime is chosen for a system, the program continues to compete for funding with other programs and thus the incentives to innovate persist, though possibly at a reduced level.

PART 4: A RENT-SEEKING MODEL DESCRIBES THE EQUILIBRIUM RESPONSE OF INNOVATION AND PROFIT TO PRIZE LEVELS

In a rent-seeking model of the sort originally analyzed by Tullock (1967), firms spend money attempting to win a prize. Even over a time horizon where entry and exit are impossible, increasing the prize level by one dollar will not simply cause firms' profits to increase by one dollar. Rather some fraction of the dollar will be channeled into increased expenditures devoted to attempting to win the prize. Over a time horizon where entry and exit are possible, changing the prize level has no effect at all on profits. When the prize level is increased by one dollar, existing firms will have an incentive to spend more money attempting to win the now larger prize. If the increase in their expenditures is less than one dollar, they will be earning positive expected profits and more firms will enter. The new entrants will also spend money attempting to win the prize. Entry will occur until aggregate rent-seeking expenditures equal the size of the prize and firms are earning zero expected profits overall.[2]

This rent-seeking formulation clearly applies to the regulatory structure in defense procurement. The existence of prizes or economic profit in the production phase of weapon programs induces firms to spend their own money attempting to win the right to produce such systems. Innovation and Congressional and executive branch lobbying are probably the two primary forms of rent-seeking activities available to defense firms. Three major conclusions follow from this rent-seeking formulation.

First, economic profit in the production phase of the acquisition process does not necessarily imply that overall profits will be positive. In fact, in the long run, if entry and exit are possible then overall economic profit must be zero. Thus in the long run profit policy has no effect at all on profits; rather it controls the level of rent-seeking expenditures.

Second, even in the short run, profit policy influences both the level of profit and the level of rent-seeking behavior.

Third, because of the existence of undesirable forms of rent-seeking behavior, such as Congressional lobbying, the policy of inducing innovation through prizes on production contracts is not perfect. However, as argued in Parts 1 to 3 above, the DoD may have no other alternative, explaining why the policy is used. This does suggest that

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[2]See Rogerson (1988) for a formal rent-seeking model that illustrates these points.

the DoD should attempt to directly purchase innovative activity when possible. Furthermore, it raises the issue of whether the DoD can implement policies that channel rent-seeking behavior into innovation and away from other less-desirable forms of behavior.

3. IMPLICATIONS FOR REGULATORY POLICY

This section outlines eight implications of this theory for how procurement policy should be optimally structured. It does not attempt to explore all the implications of this theory for regulatory policy. Such an analysis would require a detailed description and consideration of the current rules for determining prices, which is beyond the scope of this study. This section simply shows that the idea of "prizes for innovation" is an extremely useful organizing principle for examining regulatory issues in defense contracting.

IMPLICATION 1: AN IMPORTANT FUNCTION OF PROFIT POLICY IS TO CONTROL THE RATE OF INNOVATION

An ongoing and seemingly never-ending debate in policymaking circles in Washington concerns whether defense profits are too high or too low and whether price levels allowed under profit policy should be adjusted to correct this problem. Every few years, Congress (usually through the General Accounting Office) or the DoD produces a new calculation of accounting rates of return and the debate begins again.[1] The debate over whether price levels should be raised or lowered then examines the problems with using accounting-based numbers and what a "fair" profit rate should be. The implicit assumption, which all sides in the debate seem to agree on, is that the only effect of raising (lowering) allowed profit levels on production by some amount would be to raise (lower) firms' overall profit levels by the same amount and possibly induce some entry or exit. Since profit policy is seen simply as a tool for regulating firms' overall profit levels, the debate is on whether overall profits appear too high or too low.

If this study's theory is correct, an important function of profit policy may be to regulate the level of innovative activity in the defense sector. Therefore, an important focus of the debate should be whether there is currently an adequate level of innovation. Even if entry into and exit from the defense sector were impossible, a share of any increase in profit levels earned on production contracts will be transformed into increased innovative activity. If entry and exit are possible, long-run profits will necessarily be zero. Thus, profit policy

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[1]Comptroller General of the United States (1971, 1986) and DoD (1976, 1985) are the major such studies since 1970. See Bohi (1973), Burns (1972), Hall (1967, 1968), and Stigler and Friedland (1971) for economists' analyses of some of these issues.

has no effect at all on long-run profits. The only long-run effect of profit policy is to determine the level of rent-seeking expenditures.

There is almost no evidence on the difficulty of entry into the defense industry. The only existing data show that, if anything, rates of turnover of firms in the defense sector appear to be higher than in similar nondefense industries.[2] It may be that potential entrants are able to establish a "toehold" in the industry by first becoming a sub-contractor—i.e., producing a subsystem of a major weapon system under contract to one of the larger prime contractors dealing directly with the government. Between 50 and 60 percent of a weapon system is normally subcontracted by the prime contractor.[3] A firm can therefore enter the industry and gain experience without initially having to commit massive amounts of capital. However, such old data and a qualitative argument are obviously not totally convincing, and more evidence needs to be gathered on this point.

Overall positive or negative profits in a given year are not inconsistent with the claim that profits are on average zero. Industry profit will tend to vary from year to year for various reasons. Existing pricing rules probably do not fully reflect changes in market rates of interest. Thus profits are above (below) average when market interest rates are low (high).[4] Prices of widely used inputs in the defense sector may rise (fall) unexpectedly, thus reducing (increasing) the profits of all firms that had signed fixed-price contracts not anticipating the change. Finally, recall that relative bargaining power together with the pricing rules determine firms' actual profit levels. In times of military buildup when excess capacity dwindles, firms' bargaining power increases and profit levels appear to rise.[5]

Much of the ongoing debate on profit policy can thus be viewed as attempts to "even out" these yearly variations in industry profit levels. This may be a good idea and deserves further formal investigation. However, the debate should also be concerned with the effect that long-run average profit levels are having on innovation.

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[2]Peck and Scherer, 1962, pp. 123–128.

[3]Gansler (1980), p. 127.

[4]See Rogerson (1992b).

[5]DoD (1985) provides some evidence on this point. See Greer and Liao (1986) for an extremely interesting empirical demonstration that excess capacity affects profitability.

IMPLICATION 2: THE CORRECT REGULATORY PRINCIPLE MAY BE TO SET PRICE EQUAL TO FULL COST PLUS A PERCENTAGE OF FULL COST WHERE "FULL COST" MEANS OPERATING COST PLUS CAPITAL COST

Let OC denote the operating cost of producing a particular weapon, K the capital stock used in producing it, and r the normal rate of return on capital.[6] Then the pricing rule being suggested is

$$p = (1 + \gamma)(OC + rK), \quad\quad (3.1)$$

where γ is a positive real number. Thus, the price equals the full cost of production plus a percentage of full cost. This scheme clearly establishes prizes for innovation, but so would many other pricing schemes. Two desirable features may make it the preferable rule.

The first feature is that the prize is bigger for projects involving greater expense. This might be thought to roughly insure that firms producing more useful innovations will receive larger prizes. Even after a design is initially judged successful and the DoD decides to produce and purchase it, more information on the value of the new system will be forthcoming as it begins to be used in the field. Systems that ultimately prove most valuable will be purchased in greater quantities over a longer period of time. Larger prizes will be paid to systems that ultimately prove to be most useful. Further, there is probably a sense in which innovation affecting a $30 billion program is more important than innovation affecting a $30 million program.

Many pricing schemes other than the one in Eq. (3.1) would have the property of awarding larger programs bigger prices. For example, until the mid-1970s, the DoD's pricing rule probably more closely resembled the following:

$$p = (1 + \gamma)OC . \quad\quad (3.2)$$

The markup γ was chosen large enough not only to cover capital costs but also to provide a prize. Currently, the DoD's pricing rule probably is closer to the following:[7]

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[6]There are extremely important conceptual and practical issues involved in determining all three of these values. For example, much weapon production involves considerable amounts of joint operating and capital costs. The following discussion does not consider these issues. It is simply assumed that OC, K, and r have been determined. See Rogerson (1992b, 1992c) for further discussion of these issues.

[7]See Rogerson (1992b).

$$p = (1 + \gamma)OC + rK . \tag{3.3}$$

Capital costs are explicitly accounted for and reimbursed. However, the measure of "size" is still operating cost. An alternative rule that might appeal to economists involved in rate of return regulation would be to give firms a higher rate of return on production contracts. This would be implemented by the following sort of rule:

$$p = OC + (1 + \gamma)rK . \tag{3.4}$$

Even though all of these rules provide larger prizes for larger projects, only Eq. (3.1) exhibits a second desirable feature that the firm has no incentive to distort its mix of capital and noncapital expenditures away from the minimum cost ratio.[8] Equation (3.1) provides an equal profit for the firm whether the firm spends it on operating costs or capital costs. The other rules provide a greater profit for one of the two inputs and thus bias the firm's choice in favor of the more highly rewarded input. This result is standard in the literature on the behavior of the profit-maximizing firm under regulatory constraint so will not be formally derived here.[9]

IMPLICATION 3: THERE MAY BE A TRADEOFF BETWEEN ENCOURAGING INNOVATION AND ENCOURAGING PRODUCTIVE EFFICIENCY

The remarks under Implication 2 demonstrate that prizes for innovation can be created without necessarily biasing the firm's capital-labor choice. However, all the pricing rules discussed above, including Eq. (3.1) have the property that firms incurring higher costs will also earn higher profits. This was argued to be a desirable feature of a system that attempts to award larger prizes to more important innovations. However, it will also give firms the incentive to attempt to maximize production cost once they have been selected to produce a system. Thus the most natural method of implementing a prize system may also, unfortunately, create disincentives for firms to minimize production cost. How to design pricing rules that simultaneously deal with creating prizes for innovation and incentives to minimize production cost is clearly an important topic for future research.

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[8]See Teresawa (1984), pp. 4-1 to 4-4; Rogerson (1984, 1992b), and Tirole (1986) for analyses of a different factor affecting the firm's capital vs. noncapital input choice. This is that the firms may be subject to a "hold-up" problem.

[9]See Baily (1973) for a very nice treatment of this type of model as well as for references to the voluminous literature.

IMPLICATION 4: POLICIES THAT REDUCE ECONOMIC PROFIT ON PRODUCTION CONTRACTS MAY REDUCE INNOVATION

Two examples of such policies will be considered, dual-sourcing and buy-ins.

Dual Sourcing

Dual-sourcing involves having two firms build separate assembly lines for the same weapon system and then competitively bid for shares of successive annual production lots. Congressional pressure made this a common practice for procurement of missiles in the 1980s.[10] The standard analysis of the costs and benefits of this practice is as follows. The cost is that the nonrecurring expenses of setting up the production facility must be incurred twice. A not quite so obvious cost is that the individual firms will move more slowly down their learning curves given that they are splitting production. A benefit is that firms will strive to minimize production costs as part of the competition to win more production. Another benefit is that any economic profit that would have been earned in a sole-source situation will be competed away.

From the perspective of this report the second cited benefit may in fact be an additional cost. The removal of all economic profit on production contracts will also remove firms' incentives to innovate in an effort to win them. Dual-sourcing therefore illustrates the point made in Implication 3. Although dual-sourcing may encourage productive efficiency, it may also discourage future innovation. See Riordan and Sappington (1989) for a theoretical model analyzing this idea.

Buy-Ins

The term "buy-in" is used in the literature to describe two different practices by firms. The first is where a firm purposely bids well below its expected cost on a production contract, with the intention that government will bail the firm out when it becomes clear that the price was much too low. The second practice is where a firm purposely bids well below its expected cost for the first annual production contract of a new system to win the right to be the prime contractor. The firm expects to lose money on the first contract but hopes to recover its

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[10]See Burnett and Kovacic (1989) for an excellent description of current dual-sourcing practices. Also see Anton and Yao (1987); Seshadri, Chatterjee, and Lilien (1987); and Riordan and Sappington (1989) for theoretical models.

profit by earning positive economic profit on all subsequent annual production contracts, which will be negotiated in a sole-source environment.

The first practice is clearly undesirable. However, this study's theory suggests that the second practice may not be desirable either. Suppose that the winning prime contractor expects to earn $20 million in discounted profit by taking advantage of profit policy's generous rules and its sole-source position. An economist's initial reaction might be that having an auction where the right to be the prime contractor was auctioned off for $20 million would be the ideal solution to the "problem" of economic profit on production contracts. This is exactly what a competitive buy-in situation would accomplish.

However, this view ignores the possibility that economic profit on production contracts may be a desirable feature of the current system. A government policy of actively encouraging firms to bid well below their cost on initial production contracts may not be a good policy if the current level of economic profit earned on production contracts is generating a correct level of innovation. Rather, a policy where the DoD attempts to select the firm based on its predicted production cost and design quality may be more appropriate.

IMPLICATION 5: THE CURRENT REGULATORY SYSTEM ENCOURAGES VERTICAL INTEGRATION OF INNOVATION AND PRODUCTION

Firms that design new weapons will have an incentive to integrate downstream into production if the rewards for excellent designs are in the form of profits on production contracts. Thus the vertical integration of the R&D and production functions in the U.S. defense industry may be due to the regulatory structure rather than to any natural economic advantage of performing both functions within the same firm. This suggests that it would be interesting to investigate how separately the R&D and production functions are organized within the same firm.

IMPLICATION 6: DIFFERENT PRICING RULES MAY BE APPROPRIATE FOR DIFFERENT SECTORS OF THE DEFENSE INDUSTRY

Current profit policy rules are intended to apply uniformly to all defense contracts. However, the need and importance of innovation vary among sectors in the defense industry. This suggests pricing rules should vary from sector to sector depending on how much inno-

vative activity is required. In particular, pricing rules for more standard products should provide less economic profit.

IMPLICATION 7: IT COULD BE DIFFICULT TO PROVIDE ADEQUATE PRIZES IF THE DEFENSE SECTOR WAS PUBLICLY OWNED

It is periodically suggested that the defense sector should be nationalized.[11] The theory of this report suggests a possible problem with this idea. Namely, it is probably difficult to award large prizes to executives of nationalized companies. At a minimum this is an issue that would have to be carefully studied and dealt with by any nationalization scheme.

IMPLICATION 8: THE ROLE OF THE IR&D PROGRAM

The DoD encourages firms to spend money on innovation not only by creating prizes but also by directly subsidizing this activity. Through the Independent Research and Development (IR&D) program the DoD pays for an agreed-upon fraction of defense firms' expenditures on independently chosen and conducted research programs.[12] The theory of this research suggests two reasons why this extra policy may be useful.

First, as explained in Sec. 2, inducing innovation through prizes tends to cause other less-desirable forms of rent-seeking behavior in addition to innovation. It would be better to create a policy that channelled more of the rent-seeking behavior toward innovation. The obvious method for doing this is to subsidize expenditures on innovation and tax expenditures on other rent-seeking activities such as lobbying. The IR&D program accomplishes the former objective. The latter objective is accomplished to some extent by regulations that make lobbying expenditures unallowable for purposes of costing defense contracts.[13]

Second, compared to private industries where innovation is important, such as the pharmaceutical industry, the prize levels in defense probably do not vary as much with the quality of the innovation. A firm producing an extremely useful new drug may earn profit mar-

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[11]See, for example, Galbraith (1969).

[12]See Adams (1981), ch. 7; and Lichtenberg (1990) for further discussions of the IR&D program.

[13]See Rogerson (1992b) for a more detailed discussion of unallowable costs.

gins of well over 100 percent. However, defense firms earn fairly constant profit margins regardless of the value of their innovation. Profit policy rules prescribe that the same profit margin be paid regardless of the quality of the innovation. In practice, firms that have created more valuable innovations will probably in general have more bargaining strength, so they will earn somewhat higher profit margins. However, firms will never earn profit margins of much over 20 percent regardless of the value of their innovation. To do so would invite political problems and perhaps create a basis for prosecution regarding the accuracy of the cost estimates originally submitted by the firm. Even if there were not political problems, it might be unwise to allow contract officers a wide discretion to adjust profits depending on their perception of the value of the innovation. Since the value of the innovation is not objectively verifiable, that would invite charges (as well as actual instances) of graft and unfairness. The only objectively verifiable rule is to pay a relatively constant profit rate and thus reward better ideas only to the extent that better ideas are associated with larger projects. This suggests that it may be the case that defense firms do not have adequate incentives to devote sufficient resources to researching the most important programs to the DoD. Thus subsidizing research in these most important areas may substitute for extremely large prizes. This second theory suggests that the DoD should play a fairly active role in targeting IR&D subsidies toward particular areas, while the first theory does not.

4. ESTIMATION OF PRIZES: A NONTECHNICAL SUMMARY

This section provides a brief, nontechnical summary of Secs. 5, 6, and 7, explaining how the size of prizes that firms competed for were calculated for a group of major weapon systems. Readers not interested in the technical details can read this section and then skip to Sec. 8, which analyzes the results. Even readers who intend to read Secs. 5–7 might find this section to be a useful overview.

Data for 12 major weapon systems, the date of the award, and the identity of the winners and losers are listed in Table 6.1. For each system the stock market value of all the firms a few days before and a few days after the award announcement was determined. The size of movements in contestants' stock market value in response to the announcement of the winner can be used to infer the value of the prize that the stock market believed the winner would receive.

An example may help illustrate this idea. Suppose that two firms each have a 50 percent chance of winning a prize worth $1 million. Then the day before the announcement, each firm would be worth $500,000. The day after the announcement the winner would be worth $1 million and the loser would be worth zero. The increase in the winner's market value equals the decrease in the loser's market value. Both changes are $500,000. Furthermore, the sum of these two changes exactly equals the size of the prize they were competing for.

Section 5 shows that this type of reasoning can easily be generalized to cases where there are more than two firms and the probabilities of winning are not symmetric. The result is a formula that calculates the size of the prize as a function of

- The number of contestants.
- The vector of probabilities that each firm would win as estimated by investors a few days before the announcement.

The problem is that the latter data are, of course, not observable. The major theoretical result of Sec. 5 is to show that the formula for calculating the size of the prize produces larger estimates as the vector of probabilities becomes less symmetric. In particular then, conservative estimators can be created by choosing probabilities that are more symmetric than the real probabilities were likely to be. This study

creates two estimators by using two probability vectors. The first is the symmetric one—i.e., in an n firm contest each firm has a 1/n chance of winning. This produces the lowest possible estimates and can be interpreted as an absolute lower bound on the size of the prize. However, this is likely to underestimate the size of the prize in many cases since investors often view some firms as being more likely to win than others. Therefore one can construct a less-conservative but still reasonable estimator by assuming that every vector of probabilities is equally likely.

Section 5 develops the theory underlying the estimators. Section 6 explains how the stock market data for the 12 contests was derived. Section 7 uses the estimator with the estimates of changes in market value to calculate the size of the prize for each weapon system. Table 7 presents the estimated size of the prize averaged over all 12 contests. The value labeled π_{LOW} is the more conservative, and that labeled π_{HIGH} the less conservative estimate. An absolute lower bound on the average size of the prize is $47 million and a reasonably conservative estimate is $67 million.

Readers not interested in the technical analysis underlying these calculations could turn directly to Sec. 8.

5. ESTIMATION THEORY

There are several approaches to empirically measuring the size of the prizes created by current regulatory policy. This section will explain why two are unsatisfactory and then develop the underlying theory necessary to use a third approach, the one used in this report.[1]

OTHER APPROACHES

One obvious approach to measuring the size of prizes earned by firms would be to use accounting data to measure the return on assets earned by firms on their production activities. However, accounting measures of assets and income are inaccurate in various ways. Perhaps most important, accounting data provide a measure only of *accounting* profit. To calculate *economic* profit one must take the accounting rate of return and subtract the "normal rate of return earned by firms of this risk class." There is no noncontroversial method of calculating what a normal rate of return should be for major defense contractors.

Analysis of accounting data is the time-honored approach of the profit studies that the DoD and Congress periodically undertake. The inevitable outcome of any new such study is a fierce debate over whether the study proves that profit rates are too high or too low. An excellent example concerns the DoD's (1985) study concluding that current profit rates were approximately normal—i.e., no economic profit was being earned. The GAO (Comptroller General of the United States, 1986) responded by arguing that a "correct" analysis of exactly the same accounting data unambiguously showed that defense firms were earning large positive economic profits. The GAO and DoD disagreed on several interpretations of how to use the accounting data and also on what a normal rate of return was for defense firms.[2] Thus it is unlikely that any accounting-based measure of the size of prizes could be calculated that a majority of the defense community would widely accept as noncontroversial and correct.

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[1]See Lichtenberg (1988) for a related empirical investigation that attempts to directly estimate the amount of privately funded R&D induced by military procurement.

[2]See Comptroller General of the United States (1986) for a step-by-step description of how the GAO and DoD analyses differ.

Another approach would be to examine the pricing regulations to determine the rate of return they currently allow. This approach exhibits perhaps even more serious problems than the first. The major problem of the previous approach is also a problem here. Analysis of the pricing rules will yield only the *accounting* profit earned by firms. To calculate the *economic* profit, one must subtract a "normal" rate of return, which is difficult to determine. Further, profit policy allows fairly broad ranges of accounting profit to be earned. At best, an analysis based solely on profit policy rules would yield a fairly broad range of prizes.

Finally, the prize level earned by firms depends not only on the level of profits guaranteed by pricing rules but also on firms' bargaining power. This last problem can be explained as follows: The goal of the second approach would be to calculate the economic profit that profit policy rules allow a contractor to earn as a function of his estimated costs. Suppose it was determined that the profit rate was γ—i.e., a contractor with estimated costs of $\hat{C}$ would be allowed economic profit of $\gamma \hat{C}$.

Now suppose a firm and contracting officer are negotiating over the price that will be paid for next year's production of some weapon. They will agree on an estimate of the production cost, $\hat{C}$, which then determines the contract price, $\hat{p}$, according to the formula:

$$\hat{p} = (1 + \gamma)\hat{C} . \tag{5.1}$$

If the firm's actual costs of production turn out to be C, the firm's actual profits can be written as

$$\pi = \gamma \hat{C} + \left(\hat{C} - C\right) . \tag{5.2}$$

In particular the firm has two sources of profit. First there are markups on estimated costs, as determined by profit policy (the term γC). However, the firm can also increase its profits by producing the item for a lower cost than anticipated ($\hat{C} - C$).

A careful analysis of profit policy rules will shed light on the magnitude of only the first of these two terms. However, firms with strong bargaining power are able to substantially increase their profits by negotiating cost estimates considerably higher than what the actual costs will be. Scherer, for example, examines a large group of fixed-price production contracts and finds "an almost perfectly consistent tendency to underrun target costs or base prices." He finds the average underrun varied between 1.25 percent and 2.25 percent depend-

ing on how it was calculated.[3] Simply analyzing profit policy rules will therefore not yield a correct estimate of firms' economic profits.

USE OF STOCK MARKET DATA

It is possible to totally avoid the problems of the above two approaches with stock market data. The basic idea is to calculate the stock market value of firms competing for a prime contract award the day before the announcement of which firm won and the day after. If the winner were expected to earn zero economic profit on the production contracts, the announcement should not have affected the stock market value of the firms. However, if the winning firm was expected to earn positive economic profit, its market value should have risen and the losers' value should have fallen. Furthermore, the size of the changes in market value should be related to the size of the prize. This subsection outlines a theory describing the relationship between the observed changes in market value and the unobserved size of the prize. The theory will allow one to calculate the size of the prize associated with a given contest based on observation of the changes in market value.

This approach does not suffer from the problems of the previously described approaches. First, it does not rely on any accounting data. Second, it is directly measuring *economic* profit and not *accounting* profit. If the winning firm will earn zero economic profit on all production contracts, its market value will not change on the day of the announcement. Third, the change in market value of the firms reflects all expected changes in profits whether they are due to profit policy markups, bargaining power, or something else.

The critical assumption underlying this approach is, of course, that the market's perception of the size of the prizes is accurate. Large numbers of professional analysts closely study the defense industry. Furthermore, the award of a major new weapon system is a very prominent event that the financial community widely discusses and analyzes before the award date. Because of government's formalized procurement procedures it is always known precisely which firms are competing to be the prime contractor for a particular system. Therefore the market value of competing firms should reflect a fairly well-considered evaluation of the economic profit the winner will earn.

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[3]Scherer (1964), p. 194.

THE MODEL

In a simple formal model of how the prize level and the contestants' probabilities of winning determine observed changes in market values, the following notation will be used:

π = The dollar value of the prize that firms are competing for.[4]

n = The number of firms competing.

q = The probability as evaluated by the market that no firm will win and that the project will be canceled.[5]

p_i = The market's evaluation of the probability that firm i will win the contest conditional on the project not being canceled. Thus each p_i is between zero and one and the p_is sum to one.

p = The vector of probabilities $(p_1, \ldots, p_n)$.

p^* = The vector of probabilities $(1/n, \ldots, 1/n)$—i.e., when $p = p^*$ each firm has an equal chance of winning.

M_i^B = The market value of firm i on the day before the winner is announced.

M_i^A = The market value of firm i on the day after the winner is announced.

V_i = The change in the market value of firm i, $M_i^A - M_i^B$.

V_W = The change in the market value of the winner.

V_L = The sum of the change in the market value of the losers.

W = The index number of the winning firm.

It is important to note which variables can and cannot be directly measured. Obviously π cannot be directly measured. Neither can p or q. All the other variables are directly measurable.

For simplicity it will be assumed that stock prices move for no other reasons than the announcement of the winner. In reality, stock prices

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[4] The theory does not change if the possibility that different firms will receive different sized prizes is allowed for. It can be assumed that each firm i will receive a price π_i if it wins, where the π_i are determined before the contest as independent draws from a distribution with mean π, and the same formulas still apply.

[5] The data suggest that q is quite close to zero. The empirical estimates would not change greatly if it were simply assumed that q equaled zero. However, allowing a positive value of q does not complicate the model, so this possibility is allowed for. Also, positive values of q in the formal model make it clear how to test if q equals zero.

change for a variety of other reasons. Formally this could be captured by assuming that the values of V_i are observed with only random error. It is straightforward to generalize the analysis in this fashion and show that the same formulas still apply.

It will be assumed that investors are risk-neutral with respect to the risk of which (if any) firm will win the contract. This seems reasonable since the contest risk is clearly idiosyncratic and thus diversifiable.[6]

An estimator of π is simply a real-valued function that maps the directly observable variables into an estimate of π. Formally, an estimator is therefore a function of $(V_1, \ldots, V_n)$ and W. Let e $(V_1, \ldots, V_n$ W) denote an estimator. A good estimator is unbiased in the sense that it will on average estimate the size of the prize correctly.

All the data analyzed in Sec. 6 are for contests that were not canceled. Thus there is a sort of "survivor bias" in the data that one must formally deal with by calculating expected values of estimators conditional on the project not being canceled. Let E(/p,q) denote the expectation operator given p and q conditional on the project not being canceled. An unbiased estimator can now be defined.

The estimator e is unbiased given p and q if

$$E\big(e(V_1, \ldots, V_n, W)/p,q\big) = \pi . \tag{5.3}$$

If an estimator is conservative in the sense that it tends to underestimate the size of π, this will also be useful, since a conservative estimator will establish a lower bound for π.

The estimator e is conservative given p and q if

$$E\big(e(V_1, \ldots, V_n, W)/p,q\big) \le \pi . \tag{5.4}$$

The estimator is strictly conservative if the inequality in Eq. (5.4) is strict.

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[6]It will be shown below that under the assumption of risk neutrality V_W should be greater than or equal to V_L in absolute value with strict inequality being interpreted as evidence that q > 0. It is straightforward to relax the assumption of risk neutrality and show that risk aversion will also cause this inequality to be strict. (The intuition is straightforward. If investors are risk-averse, the resolution of uncertainty because of the announcement should cause the aggregate value of contestants to rise.) As will be seen below, the data support the conclusion that V_W equals V_L in absolute value. This suggests not only that q = 0 (the conclusion drawn in the body of the report) but also that investors are risk-neutral with respect to the announcement risk. I would like to thank RAND colleague Frank Camm for pointing this out to me.

Finally recall that p and q are not directly observable. Therefore it will be important to attempt to establish that an estimator is unbiased or conservative independent of p and/or q. Such estimators will be called uniformly unbiased or uniformly conservative.

An estimator e is

uniformly unbiased over p given q		(5.3) holds for every p
uniformly unbiased over q given p	if	(5.3) holds for every q
uniformly unbiased over p and q		(5.3) holds for every p and q.

An estimator e is

uniformly conservative over p given q		(5.4) holds for every p
uniformly conservative over q given p	if	(5.4) holds for every q
uniformly conservative over p and q		(5.4) holds for every p and q.

ANALYSIS OF THE MODEL

Consider the situation on the day before the prize is awarded. Firm i has a $(1-q)p_i$ probability of winning the prize π. Thus its market value is $(1-q)p_i\pi$ higher than it otherwise would be.[7] Now consider the situation the day after the award. Suppose firm j won. Firm j's market value will increase to be π greater than it otherwise would be. All the losing firms' values will drop back down to zero above what they otherwise would be. This proves the following proposition.

Proposition 1

Suppose firm j wins. Then

$$V_i = \begin{cases} \left[1 - p_j(1-q)\right]\pi, & i = j \\ -p_i(1-q)\pi, & i \neq j \end{cases} . \qquad (5.5)$$

Proof: as above. QED.

An immediate corollary of this is the following.

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[7]"Otherwise would be" means the market value the firm would exhibit if it were not involved in the contest.

Corollary 1

No matter which firm wins,

$$V_W + V_L = \pi .\qquad\qquad(5.6)$$

Therefore

$$
\begin{aligned}
&(\text{i})\quad && V_W > -V_L &&\text{if}&& q > 0 .\\
&(\text{ii})\quad && V_W = -V_L &&\text{if}&& q = 0 .
\end{aligned}
$$

Proof: This follows immediately from Proposition 1. QED.

The observed increase in the market value of the winner should always be greater than or equal to the sum of the observed decrease in the market values of the losers, and strict inequality is evidence that $q > 0$—i.e., the market perceived some positive probability that no winner would be announced and the project would be canceled.

There is a very natural intuitive explanation for Corollary 1 based on an arbitrage argument. First suppose that q equals zero—i.e., one of the n competitors will definitely receive π. Suppose an investor purchased 100 percent of the stock of all n companies. Then the investor would definitely receive π dollars on the day of the announcement. Therefore on the day before the announcement the sum of the market values of the n firms must be π dollars higher than it otherwise would be. Of course after the announcement the winner's market value is π dollars higher than it otherwise would be and the losers' market values are equal to zero above what they otherwise would be. Thus the sum of the market values of the n firms after the announcement is also equal to π above what it otherwise would be. Since the sum of the market value of the n firms is the same before and after the announcement, the increase in the value of the winner must exactly equal the decrease of the value of the loser.

When $q = 0$, an announcement that a particular firm has won produces no news from the standpoint of the value of all n firms. It was already known that one of the n firms would win and this was incorporated into the market's estimate of the aggregate value of the firms. However when $q > 0$, there is a chance that no firm will win and the project will be canceled. An announcement that a particular firm has won produces new information from the standpoint of all n firms. The project will not be canceled, and one of the firms will receive π. The aggregate value of all firms should increase from $(1 - q)\pi$ to π above what it otherwise would be or, equivalently, $V_W + V_L$ should equal $q\pi$. This is the result of Corollary 1.

The next step in determining a useful estimator of π is to calculate the expected value of V_W and V_L.

Proposition 2

$$E\left(V_W/p,q\right) = \left[(1-q)\sum_{i=1}^{n} p_i\left(1-p_i\right)\right]\pi + q\pi \ . \qquad (5.7)$$

$$E\left(-V_L/p,q\right) = \left[(1-q)\sum_{i=1}^{n} p_i\left(1-p_i\right)\right]\pi \ . \qquad (5.8)$$

Proof: Expression (5.8) follows immediately from Eqs. (5.6) and (5.7). Therefore it is sufficient to prove Eq. (5.7). If firm i wins, V_W will equal $[1 - p_i(1 - q)]\pi$ by Eq. (5.5). Firm i will win with probability p_i conditional on some firm winning. Therefore the expected value of V_W is given by

$$\sum_{i=1}^{n} p_i\left[1 - p_i(1-q)\right]\pi \ . \qquad (5.9)$$

This can be rewritten as Eq. (5.7). QED.

A useful estimator of π can now be constructed. Let $k(p)$ denote the function

$$k(p) = \frac{1}{\displaystyle\sum_{i=1}^{n} p_i\left(1-p_i\right)} \ . \qquad (5.10)$$

Then define a class of estimators e_p as follows:

$$e_p = V_W + V_L - k(p)V_L \ . \qquad (5.11)$$

Proposition 3

e_p is uniformly unbiased over q given p.

Proof: From Eq. (5.11)

$$E\left(e_p/p,q\right) = E\left(V_W/p,q\right) + E\left(V_L/p,q\right)$$
$$-k(p)E\left(V_L/p,q\right) \ . \qquad (5.12)$$

Substitution of Eqs. (5.7) and (5.8) into Eq. (5.12) shows that $E(e_p / p, q) = \pi$. QED.

The only difference between the estimators in the e_p class is the size of $k(p)$. If $k(p)$ is larger, the estimator produces larger estimates of π. From Eq. (5.10) it is easy to see that $k(p)$ can be interpreted as a measure of the asymmetry of p. It is minimized if p is perfectly symmetric—i.e., $p = p^*$. (Recall p^* is defined as $(1/n, \ldots, 1/n)$.) It equals infinity if $p_i = 1$ for some i. The reason for this can be traced back to Eqs. (5.7) and (5.8), which show that more asymmetric contests produce smaller expected changes in market values of the contestants.

This suggests two possible approaches for constructing plausible estimates of π given that p cannot be directly measured. The first would be to use e_p^*, which always produces the smallest estimates within the e_p class. Proposition 4 shows that e_p^* is in fact uniformly conservative over p and q.

Proposition 4

(i) $\quad k\left(p^*\right) = \dfrac{n}{n-1}$.

(ii) $\quad$ Therefore $e = p^*$ is defined by

$$e_p^* = V_W + V_L - V_L \frac{n}{n-1} . \tag{5.13}$$

(iii) $\quad e_p^*$ is uniformly conservative over p and q.

Proof: Parts (i) and (ii) are straightforward. To prove part (iii), first note that $k(p)$ is minimized by choosing $p = (1/n, \ldots, 1/n)$. Therefore

$$e_p^* \leq e_p \tag{5.14}$$

for every p. This means that

$$E\left(e_p^*/p, q\right) \leq E\left(e_p/p, q\right) \tag{5.15}$$

for every p. But the RHS of Eq. (5.15) equals π by Proposition 3. QED.

Proposition 4 thus provides an extremely conservative method for estimating π. If every entrant has an equal chance of winning, then e_p^* is an unbiased estimator. For any other p, e_p^* will underestimate π.

This is a useful estimator because it provides an unambiguous lower bound on the size of π. However, for the 12 contests considered, not every contestant had an equal chance of winning every contest. Therefore e_p^* will probably underestimate the true size of the prize. It might be useful to calculate another, less-conservative estimate.

The estimator ep* is constructed by assuming that p is absolutely symmetric so that k(p) is minimized. If p is assumed to be less symmetric, k(p) will rise and a less-conservative estimator is produced. Therefore one possible approach for constructing a less-conservative but still plausible estimator would be to assume that p was somewhat less symmetric. A natural assumption to make is that p is drawn from a uniform distribution—i.e., every p is equally likely. Let E (/u,q) denote the expectation operator conditional on the project not being canceled given that p is distributed uniformly and for a given q.

An estimator e is said to be unbiased uniformly over q given u

$$E(e/u,q) = \pi \qquad (5.16)$$

for every q.

Now define the estimator e_u by

$$e_u = V_W + V_L - k(u)V_L , \qquad (5.17)$$

where

$$k(u) = \frac{n+1}{n-1} . \qquad (5.18a)$$

Proposition 5 shows that e = u is unbiased in the above sense.

Proposition 5

The estimator e_u is unbiased uniformly over q given u.

Proof: Straightforward but tedious calculus shows that

$$E\left(\sum_{i=1}^{n} p_i(1)p_i/u,q \right) = \frac{n-1}{n+1} . \qquad (5.18b)$$

Now from Eq. (5.17)

$$E(e_u/u,q) = E(V_W + V_L/u,q) - \frac{n+1}{n-1}E(V_L/u,q) . \qquad (5.19)$$

Substitution of Eqs. (5.7) and (5.8) into Eq. (5.19) yields

$$E\left(e_u/u,q\right) = q\pi + \frac{n+1}{n-1}(1-q)\pi E\left(\sum_{i=1}^{n} p_i(1-p_i)\,/\,u,q\right).\qquad(5.20)$$

Substitution of Eq. (5.18) into Eq. (5.20) yields the desired result. QED.

Note that e_u is of the same form as e_p^*. They both equal $(V_W + V_L)$ plus a constant times $-V_L$. However, $k(u)$ is greater than $k(p^*)$. Thus e_u does produce somewhat larger estimates of π. It is easy to show, in fact, that $k(u)$ is the expected value of $k(p)$ given that p is uniformly distributed.

For all the contests considered in Sec. 6 there are either two or three contestants. Table 5.1 shows the values of $k(p^*)$ and $k(u)$ for these two values of n.

The theory developed in this section has three testable predictions. These are that $V_W \geq 0$, $V_L \leq 0$, and $V_W \geq - V_L$. It also provides a method for testing if $q = 0$. Most important, it provides two rules for calculating π based on observed values of V_W and V_L. Sections 6 and 7 will consider data from several major aerospace contests to test the predictions, test if $q = 0$, and calculate the size of prizes offered in these contests.

Table 5.1

Values of k(p*) and k(u)

Number of contestants (n)	k(p*)	k(u)
2	2	3
3	1.5	2

6. ESTIMATION OF CHANGES IN MARKET VALUE

EVENT-STUDY METHODOLOGY

This section estimates the changes in the market values of firms competing to be the prime contractor for 12 major aerospace projects resulting from the announcement of which firm was selected to be the prime. There is a well-established methodology in the accounting and finance literatures for estimating the effect of various events on firms' market values. Such studies are called "event studies." This section will follow that basic methodology.[1]

Daily stock market data for the involved firms contained the name of the programs, the date on which a winner was announced, and the identity of the winners and losers (see Table 6.1).[2] Most of these data were contained in two RAND reports, Smith et al. (1981); and Smith and Friedman (1980). In addition the data were independently gathered directly from *Wall Street Journal* articles for every system.

Consideration was limited to one sector of the defense industry simply for tractability. The aerospace sector was chosen because of the large number of major contests, and innovation is clearly an important factor. Attention had to be limited to contests in 1963 or after as that is when daily stock returns from the CRSP files are available. The 12 projects considered include every major aerospace system that could be identified since 1963 for which a prime contractor was selected from a well-defined competition among two or more firms, except for the Apache AH-64 helicopter. That could not be included because the winner of the competition, Hughes Helicopter, was privately owned at the time of the award so no stock market data were available.

The naive (and most straightforward) approach to calculating the change in market value for a given firm would be simply to take the difference between the firm's market value before and after the event. However, this naive approach has two major problems. First, it ignores the effects of marketwide movements in stock prices. Second, it does not provide a precise method for determining whether an ob-

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[1]See Brown and Warner (1980, 1985) for detailed theoretical analyses of this methodology as well as for other references.

[2]See Center for Research in Security Prices (CRSP) (1986) for a detailed description of the data.

Table 6.1

Description of Events

Program	Date	Winner	Loser
F-14	69/01/15	Grumman	McDonnell Douglas
S-3	69/08/01	Lockheed	G.D.
E-3A	70/07/08	Boeing	McDonnell Douglas
A-10	73/01/18	Fairchild	Northrop
F-16	75/01/13	G.D.	Northrop
UH-60	76/12/23	United Technologies (Sikorsky)	Boeing (Vertol)
KC-10	77/12/19	McDonnell Douglas	Boeing
A-7	64/02/11	LTV	North American Douglas
C-5A	65/09/30	Lockheed	Boeing Douglas
F-15	69/12/23	McDonnell Douglas	Fairchild Rockwell
B-1	70/06/05	Rockwell	Boeing G.D.
F-18[a]	75/05/02	McDonnell Douglas Northrop	G.D. LTV

[a]For the F-18, McDonnell Douglas and Northrop competed as a team against the team of G.D. and LTV.

served change in market value is unusually large relative to the normal variation in the market value of the firm.

The standard event-study methodology is designed to deal with both these issues. Let Y_t denote a firm's percentage return on day t and let X_t denote the percentage return for the market as a whole on day t. Then the event-study methodology is based on the assumption that a particular firm's daily return is stochastically related to the daily return of the market according to

$$Y_t^i = \alpha_i + \beta_i x_t^i + u_t^i ,$$ (6.1)

where the u_t are independent normal random variables with zero mean and variance σ_i^2. The procedure is to estimate α_i, β_i, and σ_t^2 and then use these estimates to predict what daily returns should have been on the event days given the market returns on those days. One can then factor out market-induced changes by subtracting the predicted from the actual return to get an excess return. The excess return on date t can be multiplied by the market value of the firm on

date t − 1 to yield an estimate of the change in the firm's market value on date t in excess of changes in value related to marketwide movements. Finally, the estimation procedure allows one to construct confidence intervals for the estimated excess returns so one can statistically test in a precise way whether observed daily returns were unusually large during the event days.

THE ESTIMATION OF DAILY EXCESS RETURNS

The CRSP tapes were used to construct daily percentage returns for three firms or artificial firms for each event. First, daily percentage returns for the winning firm were obtained. For the case of the F-18 a team of two firms won. Thus the artificial firm consisting of both winners was created. For each event this first firm is called the WIN firm. Second, daily percentage returns for the losing firm were obtained. When there were two losers, the percentage returns were created for the artificial firm consisting of both losers. For each event this second firm is called the LOS firm. Finally, daily percentage returns for the artificial firm consisting of all contestants were calculated. This third firm is called the TOT firm.

Relationship 6.1 was estimated for all three firms for each event using days −120 to −21 where day 0 is the announcement day.[3] Tables 6.2 and 6.3 present the aggregated results across all 12 events. Table 6.2 presents the average daily returns for the three firms. For example, the average percentage increase of the WIN firm on day 0, the announcement day, was 7.6 percent. Table 6.3 presents the t-statistics for the daily returns. The daily returns for the WIN, LOS, and TOT firms are graphed in Figs. 6.1 to 6.3. Daily returns that are significant at the 99 percent level are circled.

CHOICE OF AN EVENT WINDOW

The above data can now be used to investigate the last major question that must be answered to calculate V_W and V_L. This concerns which day or days the announcement information was incorporated into the price of the stock. Define the "event window" to be the set of days on which the announcement information was incorporated into the stock price. Let (μ, ν) denote the event window beginning on day μ and running until day ν. Thus (μ, ν) consists of $\nu - \mu + 1$ days.

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[3]In some cases another contest occurred in the days −120 to −21. In this case the regression was run on 100 days chosen further back in time to avoid the overlap.

Table 6.2

Daily Excess Returns

Date	WIN	LOS	TOT
-20	-0.0126	-0.0067	-0.0095
-19	0.0010	0.0038	0.0009
-18	0.0154	0.0032	0.0095
-17	0.0027	0.0027	0.0018
-16	0.0052	0.0022	0.0043
-15	0.0051	0.0048	0.0041
-14	0.0000	0.0024	0.0045
-13	0.0024	-0.0006	0.0005
-12	-0.0016	-0.0049	-0.0030
-11	-0.0025	-0.0008	-0.0003
-10	0.0153	-0.0005	0.0071
-9	0.0110	0.0103	0.0115
-8	0.0067	-0.0025	0.0000
-7	0.0081	-0.0079	-0.0024
-6	0.0051	0.0060	0.0069
-5	0.0007	0.0127	0.0071
-4	0.0003	0.0005	-0.0010
-3	0.0030	0.0055	0.0040
-2	0.0087	0.0069	0.0055
-1	0.0155	0.0106	0.0169
0	0.0760	-0.0284	0.0167
1	0.0098	-0.0324	-0.0107
2	-0.0168	-0.0065	-0.0119
3	-0.0231	0.0005	-0.0120
4	-0.0096	0.0056	0.0007
5	-0.0039	-0.0010	-0.0018
6	0.0018	-0.0012	0.0000
7	-0.0041	-0.0029	-0.0030
8	-0.0053	0.0005	-0.0019
9	-0.0103	-0.0108	-0.0091
10	-0.0016	-0.0096	-0.0047
11	-0.0122	-0.0049	-0.0077
12	-0.0018	0.0024	0.0023
13	-0.0017	-0.0009	-0.0013
14	0.0034	0.0003	0.0015
15	0.0002	0.0054	0.0036
16	0.0056	0.0017	0.0016
17	0.0003	-0.0017	-0.0022
18	0.0050	0.0050	0.0046
19	-0.0084	0.0059	-0.0005
20	0.0036	0.0065	0.0052

Table 6.3

t-Statistics for Daily
Excess Returns

Date	WIN	LOS	TOT
-20	-1.982	-1.280	-2.285
-19	0.157	0.726	0.216
-18	2.423	0.611	2.282
-17	0.424	0.514	0.432
-16	0.818	0.420	1.034
-15	0.794	0.907	0.975
-14	0.000	0.458	1.082
-13	0.377	-0.114	0.120
-12	-0.251	-0.932	-0.719
-11	-0.392	-0.152	-0.072
-10	2.403	-0.095	1.702
-9	1.725	1.952	2.750
-8	1.054	-0.477	0.000
-7	1.247	-1.467	-0.564
-6	0.796	1.136	1.647
-5	0.110	2.412	1.700
-4	0.047	0.095	-0.239
-3	0.472	1.051	0.962
-2	1.364	1.313	1.317
-1	2.423	2.011	4.035
0	11.853[a]	-5.370[a]	3.974[a]
1	1.540	-6.177[a]	-2.568[a]
2	-2.647[a]	-1.242	-2.863[a]
3	-3.644[a]	0.096	-2.890
4	-1.507	1.068	0.168
5	-0.615	-0.191	-0.433
6	0.283	-0.229	0.000
7	-0.643	-0.550	-0.717
8	-0.837	0.096	-0.458
9	-1.617	-2.059	-2.184
10	-0.251	-1.830	-1.127
11	-1.922	-0.936	-1.852
12	-0.283	0.457	0.552
13	-0.268	-0.172	-0.313
14	0.536	0.057	0.361
15	0.031	1.031	0.865
16	0.882	0.325	0.385
17	0.047	-0.325	-0.529
18	0.785	0.955	1.105
19	-1.324	1.128	-0.120
20	0.567	1.241	1.251

[a]Significant at the 99 percent level ($t_{.005}$ = 2.6).
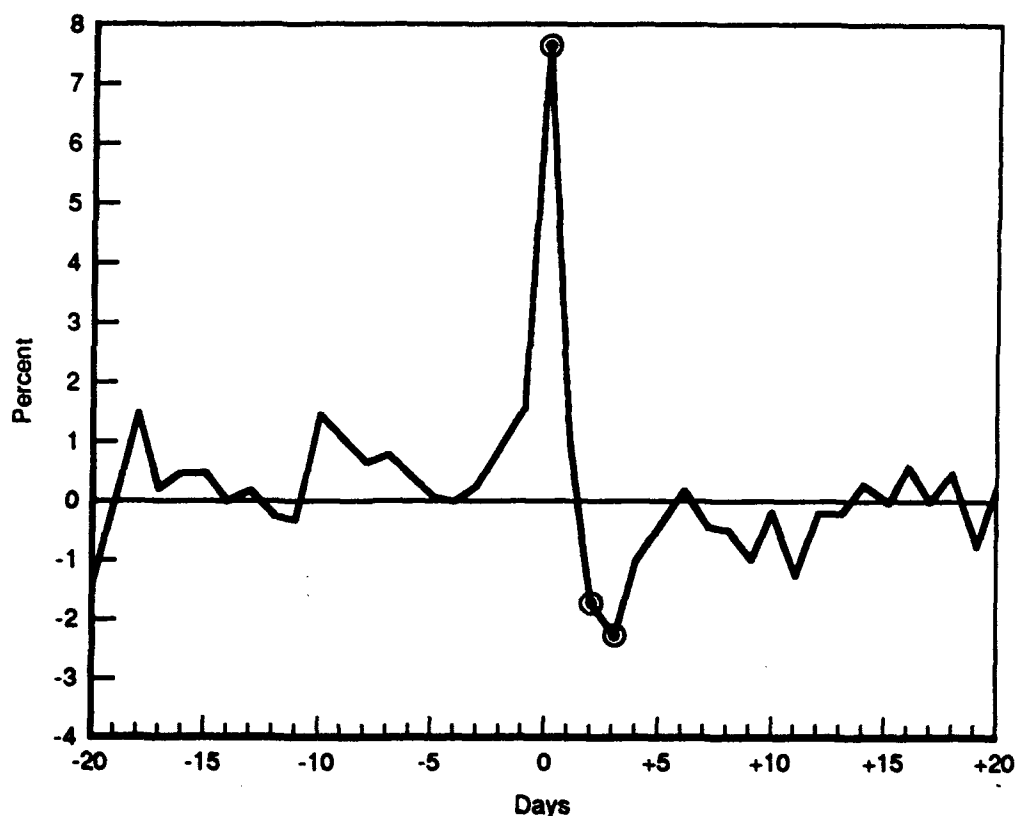
Fig. 6.1—Excess Daily Returns for Winners

A knowledge of the DoD's announcement procedures suggests that the event window should be assumed to be the two-day interval of day 0 and day 1. In theory, the DoD's formal announcement procedure is to hold a press conference to announce its decision on the formal announcement day (day 0) *after* the market has closed for the day. Thus news from this press conference should not affect the market value of firms until day 1. In practice during the period these awards were made, the DoD often informed one or more senators or members of Congress who represented the state that would benefit most from the decision, and they sometimes formally announced the decision much earlier in the day, often before the market closed. Even if the formal announcement was delayed until after the market closed, many people may have been informed of the decision through the politicians'
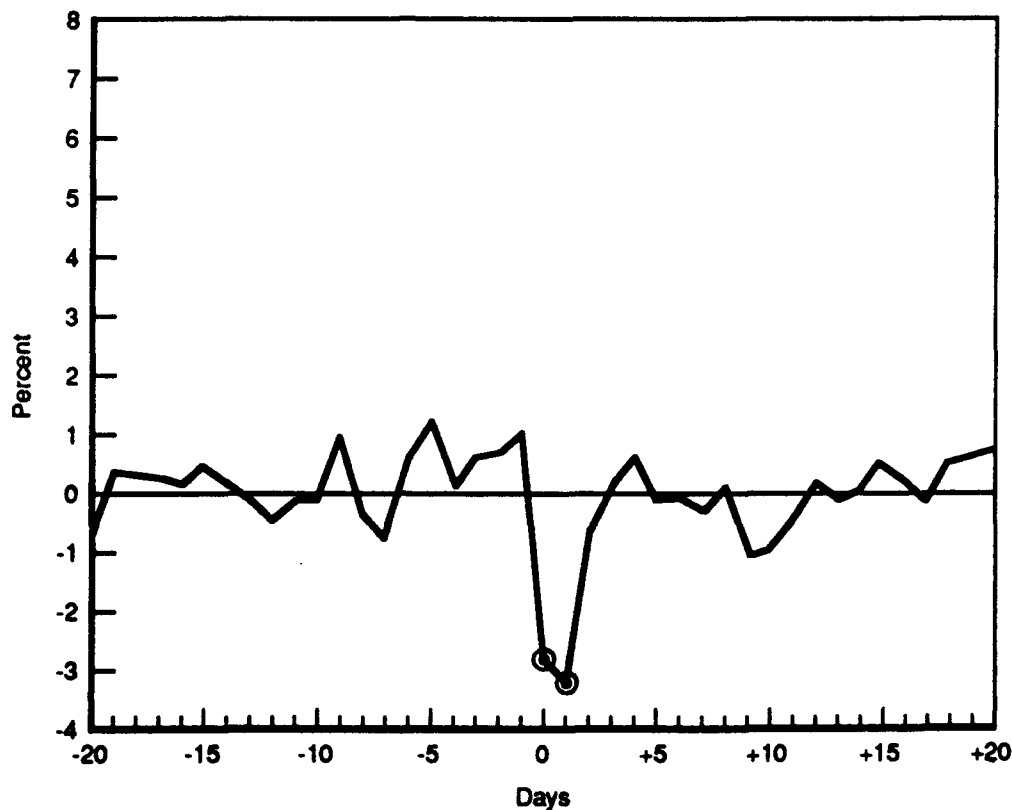
Fig. 6.2—Excess Daily Returns for Losers

offices before the market's close, and they may have used this information to trade on.[4] Thus the day when the information regarding which firm won was incorporated into the stock market value of the firm was probably day 0 or day 1 for most events. Given that it is not possible to directly ascertain which contests were announced on day 0 by a Congressional office and which were not, the correct assumption based on a knowledge of the DoD's announcement procedure would be to assume that the event occurred on days 0 and 1 for every contest.

Examination of the data in Figs. 6.1 to 6.3 provides some support for the claim that the market became aware of the announcement on day

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[4]See, for example Rice's (1971) description of the process for the C-5A award, pp. 16–17.
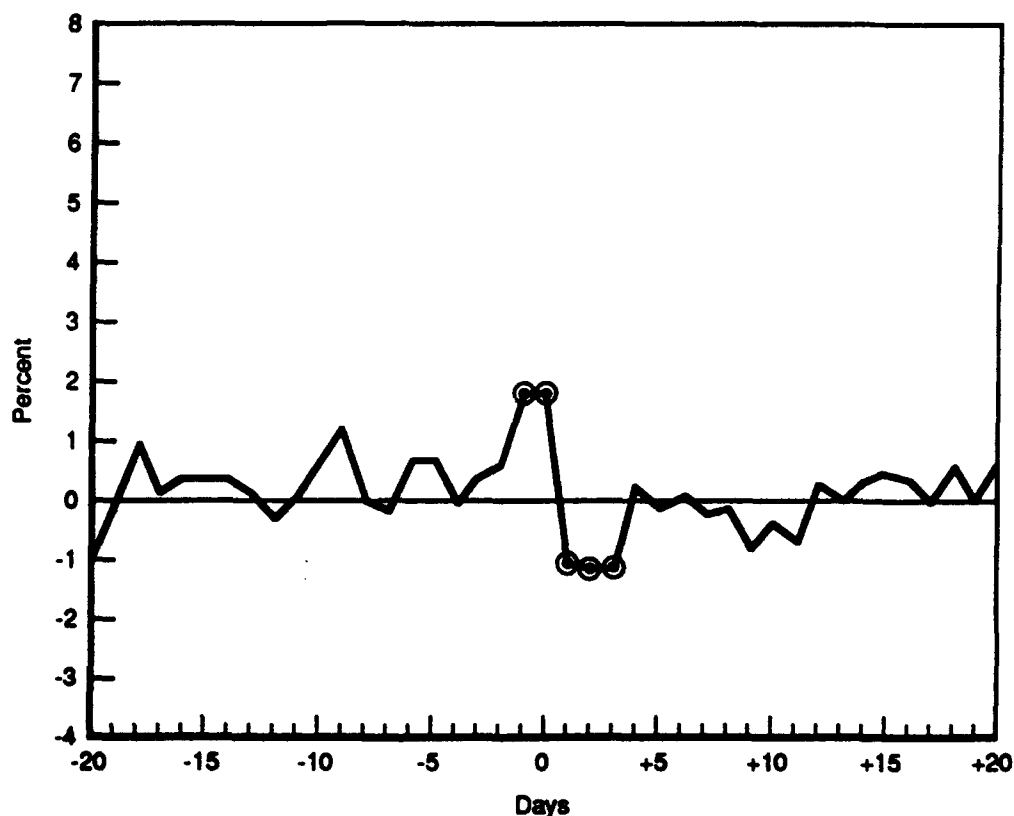
Fig. 6.3—Excess Daily Returns for Total Firms

0 or 1 for most contests. The highest daily return for the winning firms was on day 0. The return on day 1 was also positive, although not as large. For the losers, two days with statistically significant (at the 99 percent level) daily returns were days 0 and 1. The return on day 1 was even slightly larger (in absolute value) than the return on day 0.

The data also exhibit some puzzling behavior, suggesting that using the two-day event window of days 0 and 1 would not be appropriate. To understand this, first suppose that the market did become aware of the announcement of who won on day 0 or day 1 for all 12 contests. The major characteristic of the WIN, LOS, and TOT graphs would be that the daily returns would be undisturbed for every day except days 0 and 1. For the WIN (LOS) firm, the daily return on the announcement days would be significantly positive (negative). To the extent that q is greater than zero, the daily return of the TOT firm would also be somewhat positive on the announcement days.

Examination of Figs. 6.1–6.3 shows that the actual graphs depart from the stylized predicted graphs in one important qualitative fashion. The market value of *all* firms (both winners and losers) increased for two or three days before day 0 and then decreased for two days after day 1. This phenomenon is illustrated by all three graphs. It is illustrated in Fig. 6.3 which graphs daily returns for the TOT firms. The total market value of the contestants increased significantly on days –1 and 0 and decreased significantly on the following three days. Daily returns were positive for days –3 to 0 and then negative for days 1 to 3. Figure 6.2 shows that the market value of the losers increased considerably on day –1 and was somewhat positive on days –3 and –2. Figure 6.1 exhibits the same behavior. The positive returns of the winners on days 0 and 1 were followed by two days of significantly negative returns on days 2 and 3. Furthermore, returns were positive on days –3 to –1 preceding the announcement.

Thus it appears that a sort of "speculative bubble" effect occurred for the 12 contests. Prices were bid up immediately before and possibly even on the announcement day, only to crash back down immediately after. Even the market value of winners declined somewhat in days following the announcement while the market value of losers increased somewhat in the days preceding the announcement.

One must factor out the effects of this temporary surge and fall in stock prices to estimate the permanent change in firms' values resulting from the announcement. The correct procedure for doing this is to enlarge the event window to include the two or three days of abnormal returns on either side of the announcement day. In this way the calculation of changes in firms' values will ignore any price rises that were immediately negated. Including two days on either side of days 0 and 1 is necessary because the two days preceding day 0 all have fairly large positive returns and the two days following have negative returns. Returns appear more normal outside this six-day window.

The returns of firms aggregated over various possible sizes of event windows will now be presented in order to provide a more quantitative assessment of the bubble effect and how large an event window must be assumed to factor it out. Table 6.4 presents the compounded excess returns for various event windows. Table 6.5 presents the associated t-statistics.[5]

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[5]As a formal matter one can calculate a t-statistic only for the noncompounded excess return. However, because the period of event windows is so short, the compounded and noncompounded returns are almost indistinguishable. See Rogerson (1988) for a

Table 6.4

Excess Returns for Various Event Windows

μ	ν	WIN	LOS	TOT
0	1	0.0851	–0.0601	0.0057
–1	2	0.0825	–0.0558	0.0100
–2	3	0.0656	–0.0499	0.0033
–3	4	0.0580	–0.0390	0.0081
–4	5	0.0545	–0.0?~4	0.0058
–5	6	0.0582	–0.0298	0.0128
–6	7	0.0594	–0.0276	0.0165
–7	8	0.0604	–0.0342	0.0113
–8	9	0.0548	–0.0469	0.0017
–9	10	0.0656	–0.0452	0.0089
–10	11	0.0701	–0.0505	0.0084
–11	12	0.0647	–0.0487	0.0102
–12	13	0.0618	–0.0547	0.0064
–13	14	0.0685	–0.0544	0.0085
0	0	0.0760	–0.0284	0.0167
–1	1	0.1024	–0.0496	0.0226
–2	2	0.0916	–0.0501	0.0155
–3	3	0.0684	–0.0447	0.0071
–4	4	0.0584	–0.0389	0.0072
–5	5	0.0563	–0.0273	0.0133
–6	6	0.0640	–0.0244	0.0197
–7	7	0.0656	–0.0351	0.0132
–8	8	0.0664	–0.0368	0.0109
–9	9	0.0667	–0.0365	0.0133
–10	10	0.0834	–0.0455	0.0162
–11	11	0.0669	–0.0512	0.0080
–12	12	0.0631	–0.0541	0.0073
–13	13	0.0645	–0.0548	0.0070

Each table first considers the two-day event window consisting of days 0 and 1. It then expands the window 13 times by adding two days at a time (one on each side) up to the event window from –13 to +14. Then each table considers the event window consisting solely of day 0 and expands it 13 times by adding two days at a time (one on each side) up to the event window from –13 to +13.

Table 6.4 supports the conclusion of the graphical analysis that expansion of the event window by two days on either side of days 0 and 1 (i.e., so the event window is day –2 to 3) captures most of the specu-

Table 6.5

t-Statistics for Excess Returns for Various Event Windows[a]

μ	ν	WIN	LOS	TOT
0	1	9.556	−8.215	1.020
−1	2	6.682	−5.440	1.328
−2	3	4.527	−3.868	0.444
−3	4	3.552	−2.590	0.787
−4	5	3.003	−2.348	0.490
−5	6	2.856	−1.505	0.944
−6	7	2.691	−1.229	1.126
−7	8	2.629	−1.510	0.799
−8	9	2.340	−2.027	0.234
−9	10	2.557	−1.893	0.590
−10	11	2.543	−2.031	0.532
−11	12	2.296	−1.882	0.608
−12	13	2.103	−2.027	0.380
−13	14	2.201	−1.961	0.463
0	0	11.853	−5.370	3.974
−1	1	9.236	−5.552	3.188
−2	2	6.599	−4.278	1.784
−3	3	4.372	−3.175	0.778
−4	4	3.371	−2.411	0.662
−5	5	2.897	−1.496	0.986
−6	6	2.973	−1.126	1.370
−7	7	2.928	−1.585	0.944
−8	8	2.804	−1.582	0.770
−9	9	2.682	−1.519	0.867
−10	10	3.025	−1.873	0.952
−11	11	2.405	−2.019	0.505
−12	12	2.199	−2.033	0.451
−13	13	2.137	−2.008	0.401

[a] $t_{.005} = 2.6$.

lative effects in the vicinity of the announcement. Further expansion leaves the cumulative percentage changes unchanged. In the next section it will be assumed that the event window is (−2, 3).

Table 6.4 shows that simply using the two-day event window of 0 and 1 may overstate the percentage changes of the winners and losers. As the event window is expanded, the percentage changes of both the winners and losers decrease somewhat in absolute value. Figure 6.1 shows that the winners experienced large price drops on days 2 and 3 that were larger than the price rises on days −1 or −2. Expanding the window reduces the winners' percentage change. Figure 6.2 shows that the losers experienced large price increases on days −1 and −2

that were larger than price drops on days 2 or 3. Expanding the window also reduces the losers' percentage change in absolute value. Therefore, expansion of the window beyond days 0 and 1 produces a more conservative estimate of the price changes. Note that choice of a larger event window would not change the results significantly. Also note that expansion of the window around day 0 to yield event windows of the form (−t, t) yields similar results. Expansion of the window to run from day −3 to day 3 captures most of the speculative effects and yields very similar percentage changes to those from using the window (−2, 3).

Finally, some note should be taken of the statistical significance of the percentage changes as presented in Table 6.5. In general, the t-statistics become smaller in absolute value as the event window is expanded. For the first two expansions this is because the percentage changes become smaller in absolute value. However, for the remaining expansions, the percentage changes remain relatively constant. The continuing reduction of the t-statistics reflects the fact that a large percentage change is more likely to occur over a longer event window. (It is unusual for G.D. stock to fall 10 percent in one day. The same change over two years would be much less surprising.) Because of this second effect, expansion of the event window beyond (0, 1) necessarily reduces the statistical significance of the results somewhat below what they "should" be. Unfortunately, this was necessary to factor out speculative movements in the neighborhood of the announcement.

TESTS OF PREDICTIONS AND A TEST OF WHETHER q = 0

The value of V_W ($V_L, V_W + V_L$) is calculated by multiplying the market value of the WIN (LOS, TOT) firm on the day before the event by the compound percentage return of the WIN (LOS, TOT) firm over the event. Thus one can test whether V_W ($V_L, V_W + V_L$) is positive, negative, or equal to zero by testing whether the percentage return of the WIN (LOS, TOT) firm is positive, negative, or equal to zero.

The percentage changes of the WIN, LOS, and TOT firms are all strongly in accord with the theoretical predictions of the previous section. First, the percentage change of the WIN firms is significantly positive at the 99 percent level in accord with the prediction that V_W is positive. Second, the percentage change of the LOS firms is significantly negative at the 99 percent level in accord with the prediction that V_L is negative. Third, the percentage change of the TOT firms is positive but not significantly so. This agrees with the prediction that $V_W + V_L$ is nonnegative.

Finally, since the percentage return of the TOT firms is not significantly different from zero, one cannot reject the null hypothesis that q equals zero. A few days before the announcement, investors seem to have known that the program would not be canceled.[6]

ESTIMATION OF CHANGES IN MARKET VALUE

Table 6.6 presents the changes in the market value of the winners and losers for the event window (-2, 3). As explained above, one calculates the change in the market value of the winners (losers) by multiplying the compound percentage return over the event window for the WIN (LOS) firm by the market value of the WIN (LOS) firm on day -3.

The changes in market value calculated for each event are not as well-behaved as the average values. In some cases the losers' market value fell by more than the winners' rose. In a smaller number of cases, the market value of the winner or losers changed in the wrong direction; the winner's market value fell or the losers' market value

Table 6.6

Estimated Change in Market Value of Winners and Losers (thousands of dollars)

Event	V_W	V_L
F-14	8574	27613
S-3	22471	-9146
E-3A	8964	25751
A-10	6403	-13914
F-16	13592	-13013
UH-60	44727	-59619
KC-10	23836	-71616
A-7	3484	9547
C-5A	8910	-56014
F-15	42842	-56589
B-1	33128	-45062
F-18	102278	-54133
AVG	26601	-26350

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[6]Although it is not formally an unbiased estimator, one can rewrite Eq. (6.7) to obtain an estimator for q of $q = (V_W + V_L)/\pi$. Tables 6.6 and 7.1 will present, respectively, estimates for V_W and V_L and two estimates for π. Substituting these into the above equation yields estimates for q of between .004 and .005.

rose. Furthermore, although they are not reported here, t-statistics for each event were calculated and were not always significant in the predicted directions.

This is a common feature of many event studies. The large, unexplainable variance in daily stock returns makes it difficult to generate statistically significant results for each event. The standard approach is therefore to aggregate over many events.[7] For some of the 12 events, one firm may have had an extremely high probability of winning, and the favorite in fact won. In that case the announcement would have very little effect on stock prices, and normal variation might easily cause the stock prices to move in the "wrong" direction. The existence of some individual firm returns with the wrong sign in no way violates the theory.

The fact that the event-by-event results are not well-behaved raises serious questions about whether the data sample of only 12 events is large enough. An important future research topic should conduct this analysis with a larger number of events.

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[7]Although not reported here, the data in Table 6.6 were also calculated for the event windows (0, 1) and (−1, 1). In these cases most of the individual firm returns were statistically significant and of the right sign. The reasons for using the more conservative window (−2, 3) were explained above.

7. ESTIMATION OF PRIZES

Table 7.1 uses the estimator derived in Sec. 5 together with the estimates of changes in market value derived in Sec. 6 to calculate the size of prizes that firms were competing for in each event. Recall from Sec. 5 that the estimators derived were of the form

$$\left(V_W + V_L\right) - kV_L, \qquad (7.1)$$

where k is a positive number, and two methods for calculating k were selected, one more conservative than the other. The values labeled π_{LOW} and π_{HIGH} are, respectively, the values of the prize calculated using the lower (more conservative) and higher (less conservative) values of k.[1] The estimated average prize over all 12 contests is between $47 and $67 million.

Table 7.1

Average Value of Prizes Across All Contests
(thousands of dollars)

π_{LOW}	46,779
π_{HIGH}	66,957
M_B	457,249
π_{LOW} as a percent of M_B	10.2%
π_{HIGH} as a percent of M_B	14.6%
R	1,434,245
π_{LOW} as a percent of R	3.26%
π_{HIGH} as a percent of R	4.68%

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[1]The prize was calculated for each of the 12 contests separately. The average of these 12 numbers is reported in Table 7.1.

8. ANALYSIS

The natural question to ask is whether the estimated value for the prize is "large" or not. Two methods to answer this question are available. The first is to compare the prize with the average market value of the competing firm. This is done in Table 7.1. The row labeled "M_B" gives the average market value of the contestants on the day before the event (day −3). Then the next two rows give, respectively, π_{LOW} and π_{HIGH} as a percentage of the average firm value. On average the estimated prize is between 10.2 percent and 14.6 percent of the average value of the firms competing for it.

The second method is to compare the estimated prize with the expected discounted revenue stream the winning firm will receive. This is also done in Table 7.1. The rationale behind this method requires a bit more explanation. Suppose the winner will be involved in producing the weapon for T years. Let R_t denote the expected revenue that the winner will receive in year t of the project. Also assume that the owners of the firm use a discount rate of r to value these expected revenues. The discount rate reflects the time-value of money as well as any discounting due to the uncertainty of the revenue stream. Let R denote the present discounted value of revenues that the winning firm will receive. This is defined by

$$R = \sum_{t=1}^{T} \frac{R_t}{(1+r)^t} . \tag{8.1}$$

Now suppose that the firm expects to earn α dollars of economic profit on every dollar of revenue it receives (where α is between 0 and 1). Thus α is the economic profit rate that the DoD is in fact allowing. The value of the prize to the winner, denoted by π, is defined by

$$\pi = \sum_{t=1}^{T} \frac{\alpha R_t}{(1+r)^t} . \tag{8.2}$$

From Eqs. (8.1) and (8.2) it is clear that

$$\alpha = \frac{\pi}{R} . \tag{8.3}$$

That is, calculating the prize as a percentage of expected discounted revenues yields the economic profit rate firms expect to earn.[1]

The value of π has of course been estimated. It remains to estimate R to calculate α. This is done as follows. First, the DoD's estimate of the constant dollar cost of the weapon system at the time of the announcement is determined. Let C_t be the nominal dollar cost in year t, and let s be the DoD's discount factor for inflation. Then let C denote the DoD estimate of the constant dollar cost of the weapon. This is defined by

$$C = \sum_{t=1}^{T} \frac{C_t}{(1+s)^t} . \qquad (8.4)$$

The second step is to estimate R based on C. These two steps will now be described in more detail.

Since the 1970s, the DoD has been required to file a quarterly report to Congress called the Selected Acquisition Report (SAR) for each of its major weapon systems being procured. These contain the DoD's estimate of the constant-dollar cost of the program. The SAR estimate of the constant-dollar cost of the project at the time of the announcement was available for seven of the 12 systems (the F-15, B-1, A-10, F-16, UH-60, and E-3A). Four of the systems were awarded before the SAR system was put in place and thus no SAR data were available (the F-14, F-18, S-3, A-7, and C-5A). Finally, SAR data for the KC-10 were not readily available although they presumably exist.[2]

To obtain estimates of C for the five systems with no SAR data, the following procedure was used. Cost estimates for all 12 systems as reported by the *Wall Street Journal* at the time of the announcement were gathered. The *WSJ* never explicitly stated whether it was reporting a nominal or real-dollar estimate of cost. The SAR estimate of both the nominal and real-dollar cost for the seven systems with SAR data was therefore compared with the *WSJ* estimates for these seven systems. The *WSJ* estimate was always very close to the real-dollar SAR estimate. Therefore, for the remaining five systems, the *WSJ* estimate of cost was used as an estimate of C.

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[1]The prize may in fact be larger than the RHS of (8.2) because part of the value of winning the contest may be that future wins become more likely. In that case the estimator in the RHS of (8.3) may be an overestimate of α.

[2]SAR data used here were obtained from case studies described in Dews et al. (1979).

The DoD's estimate of the real cost of the system, C, may differ from the firms' calculation of expected discounted revenues, R, for three reasons. The first is that firms may expect the cost to be different from the DoD's estimate. The DoD may have purposely used an incorrect estimate of C in the SAR as part of its strategy for dealing with Congress, or the DoD and the firms may simply disagree on expected costs. No attempt was made to correct for this factor.

The second reason is that not all of the cost of a weapon system is paid to the prime contractor. The cost includes money paid directly to firms that manufacture some major subcomponents of the system. The major such item for aerospace projects is the engine. The cost also includes the value of government-supplied equipment and services. No system-by-system data on the fraction of government cost actually received by the prime contractor as revenue could be located. However, a RAND case study of the F-16 contained data for the cost of the prototype phase, which showed that 68 percent of government's cost was paid to the prime contractors.[3] Since this is the only available estimate, it will be assumed that the prime contractor received 68 percent of government's total cost figure as revenue.

The third reason that C and R may differ is that firms may use a different discount rate than the DoD—i.e., r may not equal s. The discount rate used by the DoD in its SAR reports varied between 6.58 percent and 6.86 percen. This may correct for inflation but certainly makes no allowance for any sort of risk or the time value of money. Discount rates used by firms are likely to be much higher. For example, the DoD policy group responsible for a major revision of profit regulations in 1979 assumed that firms' discount rate was 15 percent for the purposes of their analysis. This was "based on an informal survey of industry that indicated hurdle rates averaged between 15–20%. 15% was selected as a conservative number."[4]

It will be assumed that R is given by

$$R = .34\,C\,. \tag{8.5}$$

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[3]See Smith et al. (1981), p. 114. Engine manufacturing accounted for 27 percent of the total cost, and government-supplied equipment and services accounted for the remaining 5 percent.

[4]Quoted with David Koonce's permission from a personal communication from him dated December 22, 1986. During 1979, Mr. Koonce was Chairman of the DoD Contract Finance Committee. He is now Director of Financial Analysis for Martin-Marietta Corporation.

This corresponds approximately to firms using a discount rate double that of the DoD—approximately 13 or 14 percent.

The row in Table 7.1 labeled R presents the average value of R over the 12 systems calculated as described above. The next two rows present the estimate of α using, respectively, π_{LOW} and π_{HIGH}. Thus every dollar of revenue received by a prime contractor on production contracts generates somewhere between 3.26 and 4.68 cents of pure economic profit.

All the estimates calculated here are quite conservative. The more conservative estimates should be interpreted as an absolute lower bound on the size of the prizes. The least-conservative estimate presented should be interpreted as a reasonable but mildly conservative estimate. Since the conservative bias of the estimates was built in at different stages of their construction, it might be useful to summarize the sources of conservatism.

First, when the estimator functions were constructed in Sec. 5, the more conservative choice was definitely biased downward. The less conservative choice was unbiased under the fairly moderate assumption that the vector of contestants' probabilities of winning is uniformly distributed across contests—i.e., any vector is equally likely. In particular, if there tends to be a "favorite" firm in most contests, then even the less-conservative estimator will underestimate the prize.

Second, in Sec. 7 it was shown that an event window of (0, 1) should be used based on DoD announcement procedures. This produces very large changes in firms' values and thus very large estimates of the prizes. However, part of the change in value seemed to be quite temporary in that it was canceled out by compensating movements in the days immediately around the announcement. Therefore, an event window of (–2, 3) was used, which produces smaller estimates of changes in firms' values and thus smaller estimates of the prizes.

Third, in this section the discount rate of firms was assumed to be about 13 percent, which is probably moderately conservative.

9. CONCLUSION

On theoretical grounds, informational and incentive constraints inherent in the innovation process require that regulatory institutions create prizes for innovation. Since the quality of an innovation is difficult to describe or measure objectively, the most natural method for awarding prizes is to allow firms to earn positive economic profit on production contracts. Explicit recognition of this role of profit regulation generates interesting perspectives on important policy issues involving regulatory design. The values of the prizes offered on 12 major aerospace systems were calculated. The prizes are clearly large enough to support the contention that their existence is an important aspect of current regulatory structure.

This study suggests a number of interesting avenues for future research. First, the methodology developed here for using stock prices to measure the economic profit expected to be earned on a program could be used to investigate a variety of issues. For example, it is often argued that the introduction of dual-sourcing in missile procurement has lowered the profitability of these programs to firms. This study's methodology could investigate this. Second, it would be interesting to directly estimate short- and long-run elasticities of private R&D expenditure with respect to profit rates. The rent-seeking paradigm advanced here suggests that profit policy should be viewed as a tool for regulating the pace of innovation. Direct verification that R&D expenditures respond to profit levels would provide useful support for the theory. Furthermore, for policy purposes it is important to know the magnitude of the elasticities. Third, the data on daily stock returns in the neighborhood of the announcement suggest several interesting questions. Does the statistically significant pattern that prices rise before the announcement and fall afterward hold true for a larger set of contests? Do the data suggest that inside trading occurs before the formal announcement, and has this pattern changed over time? Do the data suggest that the market learns that a winner will be announced (that q equals 0) some time before the announcement day and has this pattern changed over time? Investigating these questions would require data on more contests and possibly option price data as well as stock price data. Fourth, it is important to develop a careful, formal theory of the optimal regulatory structure given that prizes for innovation must be supplied.

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